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Onset of background dynamic noise attenuates preview benefit in inefficient visual search

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ABSTRACT

When certain distractors (old items) appear before others (new items) during an inefficient visual search task, observers exclude the old items from the search (preview benefit), possibly because their locations are deprioritized relative to the locations of the new items. We examined whether participants were able to ignore task-irrelevant changes in a scene (i.e., the onset of repetitive changes, continual repetitive changes, and the cessation of repetitive changes in the background), while performing a preview search task. The results indicated that, when the noise continually changed position throughout each trial, or when dynamic noise was changed to static noise simultaneous with the appearance of the search display, the preview benefit remained. In contrast, when the static background noise was changed to dynamic background noise, simultaneous with the appearance of the search display, this task-irrelevant background event abolished the preview benefit on search efficiency. Therefore, we conclude that the onset of task-irrelevant repetitive changes in the background disrupts the process of inhibitory marking of old items.

1. Introduction

The human visual system has limited capacity, and only a small amount of information can be processed at one time. Therefore, it is necessary for the system to focus on relevant stimuli and avoid the diversion of attention to irrelevant, distracting stimuli. Such optimal functioning can be achieved by establishing an attentional set for the featural differences between relevant and irrelevant stimuli (e.g., Egeth, Virzi, & Garbart, 1984; Kaptein, Theeuwes, & van der Heijden, 1995; Sobel & Cave, 2002), and by exploiting the automatic attentional capture conferred by certain dynamic environmental signals, such as luminance changes, the abrupt onset of a new object (Franconeri, Hollingworth, & Simons, 2005; Hillstrom & Yantis, 1994; Jonides & Yantis, 1988), or the sudden initiation of motion (Abrams & Christ, 2003, 2005; Franconeri & Simons, 2003; Kawahara, Yanase, & Kitazaki, 2012; von Mühlenen & Lleras, 2007). Although previous studies have identified several principles underpinning attentional allocation, conjecture remains regarding the manner in which attentional resources are allocated to the visual field (e.g., Theeuwes et al., 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Yantis & Jonides, 1996).

One important cue underlying the allocation of attentional resources is the time at which distractors appear. It is well known that searching is easier if distractors are viewed in advance; it appears that previewed distractors are excluded from subsequent search. Therefore, the visual system must be able to distinguish newly displayed objects from those that have already been presented in the visual field, by using cues pertaining to stimulus-onset asynchrony. The ability to prioritize new over old items has been explored using a visual search paradigm known as the preview search task (Watson & Humphreys, 1997). In this task, nontargets in an inefficient search are displayed during two successive presentations, such that half of the distractors ("old items") appear during the initial presentation; following a brief stimulus-onset asynchrony ("preview period"), the remaining distractors, and a target ("new items"), are displayed at previously unoccupied locations. In this "preview condition," search efficiency, measured by reaction time (as a function of set size), is significantly improved relative to the "full-baseline condition," during which all items appear simultaneously. Search conducted under the preview condition is frequently as efficient as search during which only new items appear simultaneously ("half-baseline condition"), which suggests that previewed distractors are excluded from search. This phenomenon is referred to as the *preview benefit*.

Watson and Humphreys (1997) proposed that the preview benefit involves not only an enhanced ability to detect new items but also the active inhibition of old distractor locations via a spatial

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memory template referred to as *visual marking*. According to this perspective, irrelevant information appearing at locations in which old items were displayed previously is inhibited prior to the appearance of new items (Watson & Humphreys, 1997). Thus, irrelevant, old objects previously displayed in the visual field are deprioritized and excluded from the subsequent search. However, several studies have suggested that the preview benefit is due either to automatic attentional capture, precipitated by the onset of new items (e.g., Donk & Theeuwes, 2001), or to mere temporal grouping of new items without active inhibition of old items, resulting in the perceptual segmentation of new and old items during asynchronous presentations (e.g., Jiang, Chun, & Marks, 2002). The inhibition theory differs from the other two theories; in the former, the inhibition of old items plays a role, in addition to the enhanced detection of new items. Although these lines of evidence suggest that onset capture and temporal grouping contribute to preview benefit, in isolation they do not explain the following findings from previous studies: (1) preview benefit can be reduced or abolished by a secondary attention-demanding task imposed during the preview period (Humphreys, Watson, & Jolicœur, 2002; Olivers & Humphreys, 2002; Watson & Humphreys, 1997); (2) when a dot appears in the search display, it is easier to detect at the location of a new vs. old item (Olivers & Humphreys, 2002; Osugi, Kumada, & Kawahara, 2009; Osugi & Murakami, 2014; Watson & Humphreys, 2000); and (3) color-based inhibition appears to also affect new items of the same color as old items (Braithwaite & Humphreys, 2003; Braithwaite, Humphreys, & Hulleman, 2005), such that targets in the old color are harder to detect compared with those in a new color. Furthermore, a preview benefit also occurs for equiluminant stimuli when the preview period has a duration of 3 s (Braithwaite et al., 2006), refuting prior evidence for the absence of a preview benefit with equiluminant stimuli lacking luminance onsets. Such prior evidence has been used as initial support for the onset capture hypothesis (Donk & Theeuwes, 2001). The more recent findings demonstrating a preview effect for equiluminant stimuli are more consistent with the view that the inhibition of old items is a necessary condition for preview benefits.

One important question is whether a preview benefit occurs when an irrelevant transient change is effected in the scene simultaneous with the appearance of the search display. Because such search-task-irrelevant transient stimuli may nevertheless act as a warning signal, conveying information critical for an organism's survival, it is reasonable to suggest that attentional resources are automatically allocated to detect such a change, thereby attenuating any preview benefit in the current search task. Previous studies (e.g., Watson & Humphreys, 1997, 2002) have demonstrated that preview benefits disappear when the shape of old items is altered during the preview period, but remain during changes in color or luminance, and when old and new items differ in color. These findings suggest that transient motion, or positional shifts accompanying abrupt changes in the shape of old items, attenuate preview benefits. Furthermore, recent studies suggest that the preview benefit remains even when the shape of old items changes, provided that these changes involve either eye blink (Irwin & Humphreys, 2013; von Mühlenen, Watson, & Gunnell, 2013), occlusion (Kunar et al., 2003), or transient masking (Watson & Kunar, 2010). Osugi, Kumada, and Kawahara (2010) demonstrated that preview benefits persist during shape changes if semantic information pertaining to the items is retained. Taken together, this literature points toward a role for top-down processing in the maintenance of preview benefits, despite the presence of disruptive, bottom-up signals (see also Osugi & Kawahara, 2012).

The present study focused on the effects of another type of display change on preview benefit: we examined whether participants were able to ignore a task-irrelevant background scene change. One critical difference between laboratory and real-world search tasks concerns whether search items are presented on a blank background or on complex, visually similar backgrounds (Wolfe et al., 2002; Neider & Zelinsky, 2006). The question of whether background changes affect search performance is important for assessing the generalizability of laboratory-based findings. Furthermore, examining the effects of background changes on the preview search is a useful strategy to test whether entirely task-irrelevant changes in the scene reduce visual marking. It is possible that changes in the shape of old items (e.g., Watson & Humphreys, 1997, 2002) might increase the "targetness" (e.g., von Mühlenen & Lleras, 2007; Yantis & Egeth, 1999) of old items; i.e., attention might be directed to the locations of old items because their changes are confused with the appearance of a target. It has been argued that certain attentional capture effects might be caused by the task-irrelevant cue being perceived as a target, rather than by attention being captured by a task-irrelevant feature (e.g., von Mühlenen & Lleras, 2007; Yantis & Egeth, 1999). Therefore, it remains unclear whether visual marking is disrupted by increasing the "targetness" of old items, or by a task-irrelevant change.

To our knowledge, only one previous study directly investigated the effects of background change on the preview search. Jiang, Chun, and Marks (2002) examined whether a transient change in old items, and a background change (i.e., a change in the luminance of the old items or in the background grid color from black to white) synchronized with the onset of new items, disrupted preview benefit. The results indicated that transient changes in old items did reduce preview benefit, whereas the background change did not. This suggests that preview benefit might only be attenuated by changes within the objects themselves, rather than by changes in the background; i.e., that the mechanism underpinning visual marking can denote only marked locations, and any sudden changes occurring therein.

Due to the lack of previous research, the generalizability of the effect of background change on the preview search remains unclear. It remains possible that, if background changes are sufficiently large, they could attenuate preview benefit. A recent study demonstrated that repetitive shape changes in old items are associated with stronger reductions in preview benefit (Watson, Compton, & Bailey, 2011). Similarly, repetitive background changes may be more disruptive compared with single, transient changes.

In the present study, we examined whether changes in background reduce preview benefit. We employed static and dynamic random-noise displays, and manipulated a combination of background noises, in addition to the preview and search displays. In Experiments 1 and 2, we examined whether participants were able to ignore task-irrelevant repetitive and transient changes in the background while performing a preview search task. In Experiment 3, we assessed the number of repetitive background changes required to fully abolish preview benefit. In Experiment 4, we manipulated the onset timing of the dynamic random-noise display.

2. General methods

To determine the presence or absence of preview benefit, we compared search performance under preview, full-baseline, and half-baseline conditions. During the preview condition (Fig. 1A), the onset of old items was followed by the onset of a target and distractors, with a stimulus-onset asynchrony of 1000 ms. During the full-baseline condition (Fig. 1B), all items appeared simultaneously. During the half-baseline condition (Fig. 1C), half of the items appeared simultaneously.

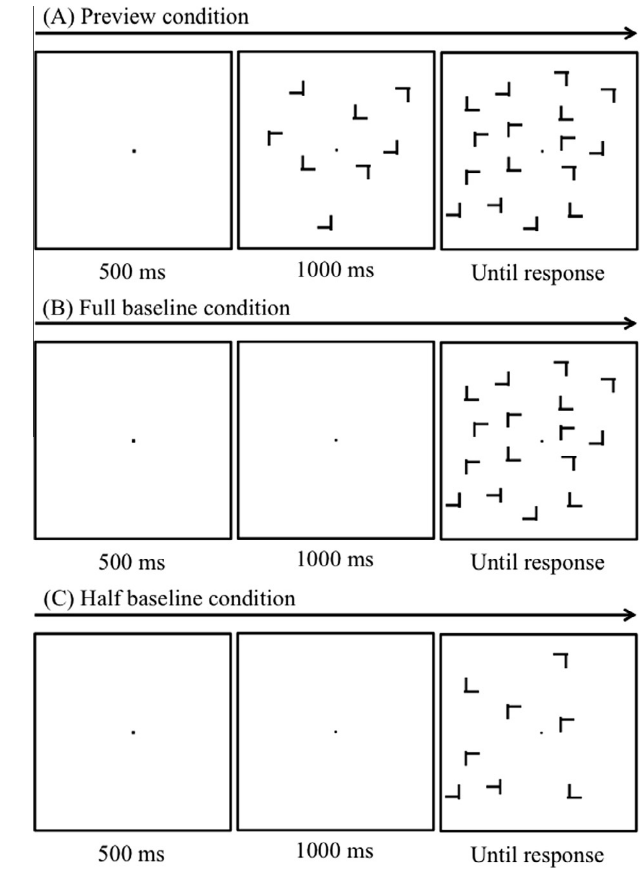

Fig. 1. Schematic diagrams of the stimulus sequences. (A) Preview condition. The old items appeared first, followed by the new items after 1000 ms; (B) full-baseline condition. All items appeared simultaneously; (C) half-baseline condition. Items used as new items in the preview condition appeared simultaneously.

2.1. Participants

All participants had normal or corrected-to-normal visual acuity. Our study followed the Declaration of Helsinki guidelines and was approved by the Ethics Committee of the Graduate School of Humanities and Sociology at the University of Tokyo. Written informed consent was obtained from all participants.

2.2. Stimuli and apparatus

The stimuli were displayed on a CRT monitor (Iiyama HM204DA, 1024 × 768 pixels, mean luminance = 19.62 cd/m^2) via the stimulus processor Bits# (Cambridge Research Systems, Kent, UK), which was controlled by a computer using the Matlab software package (MATLAB, MathWorks Inc., Natick, MA, USA) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). The refresh rate of the monitor was 60 Hz. The viewing distance was 57 cm. The monitor was gamma-corrected to achieve linear output.

The stimuli consisted of black (<0.01 cd/m^2) uppercase letters – *T*s and *L*s – subtending 0.94° in height and width. The target was a *T* rotated by either 90° or 270°; the distractors were *L*s rotated by either 0°, 90°, 180°, or 270°. The line segments forming the *L*s were offset by 0.08° at their junctions. The width of each line segment was 0.16°. The items were presented at pseudo-randomly selected locations within an invisible 7 × 7 matrix subtending 13.14° in height and width (Fig. 2). The target could appear at any of these locations with equal probability. A black (<0.01 cd/m^2) fixation dot

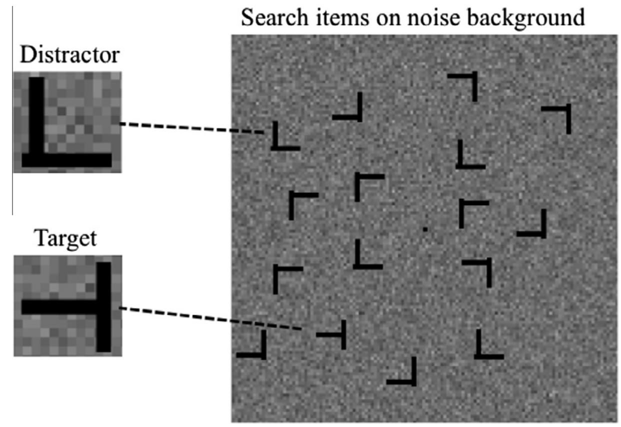

Fig. 2. An example of a search display with background noise.

(0.23° × 0.23°) was presented at the center of the display. A dynamic random noise served as a background stimulus, subtending 20.02° in height and width and resampled at 100-ms intervals. Each random noise (512 × 512 pixels) consisted of 256 × 256 dots (2 × 2 pixels each) with contrast levels sampled from a Gaussian distribution with a mean of 0, which was equivalent to a mid-gray luminance level, and a standard deviation of 12%.

2.3. Design and procedure

In Experiments 1–3, we employed a 3 × 3 design, with the following two within-subject factors: three search types ("preview search", "full-baseline search", and "half-baseline search"; Fig. 1A–C, respectively); and three set sizes (comprising 4, 8, and 16 items). Set size was manipulated in a more systematic manner in Experiment 4 (see Section 6.1). During the preview condition (Fig. 1A), a trial commenced with the presentation of a fixation dot for 500 ms; the onset of the old items was followed by the onset of new items with a stimulus-onset asynchrony of 1000 ms. The full-baseline and half-baseline conditions were identical to the preview condition, with the exception that the fixation dot was presented for 1500 ms, following which items appeared simultaneously. In each experiment, each search type was tested in a separate block. Participants completed three blocks of trials for each of the three search types. Each block consisted of 30 trials (10 for each set size). The order of presentation of the blocks was counterbalanced. Experimental blocks were preceded by three 30-trial practice blocks, for all three search types.

Participants searched for a *T* and indicated a rotation angle of 90° by pressing the "6" key, or of 270° by pressing the "4" key, on a number-pad keyboard. Reaction time was measured. At the end of each trial, feedback concerning the reaction time for target detection, and the accuracy of the *T*-orientation response ("correct" or "incorrect") was provided. When the response was incorrect or the reaction time was longer than 6000 ms, a 1000 Hz tone was presented for 20 ms; pressing the "5" key triggered the next trial.

2.4. Data analysis

Reaction times for incorrect responses and reaction times <200 ms or >6000 ms (0.3% of the data), were excluded from the analysis. A defining characteristic of the preview benefit is that the search function under the preview condition is significantly shallower than it is under the full-baseline condition. Furthermore, maximal preview benefit occurs when the search slope under the preview condition is identical to that observed under the half-baseline condition. We performed an analysis of variance (ANOVA) for reaction time, to assess whether the preview benefit was obtained in each experiment. The error rate was below 5% in all cells of the factorial design; therefore, no further analysis was performed on errors.

3. Experiment 1: do repetitive changes in the background reduce preview benefit?

In Experiment 1, we examined the effects of repetitive background changes on preview benefit by manipulating a combination of background noises during the preview and search displays (Fig. 3). If repetitive changes in background fully attenuate the preview benefit, the search slope under the preview condition should be steeper compared with the slope observed under the half-baseline condition, and should thus be more comparable to the slope observed under the full-baseline condition. In contrast, if the presence of background noise is unrelated to preview benefit, the search slope under the preview condition should be shallower than the slope of the full-baseline condition, and thus more comparable to the slope of the half-baseline condition.

3.1. Methods

Participants included the first author and an additional 11 observers (aged 19–32 years) who were naïve to the purpose of the study. In Experiment 1A, we tested whether preview benefit occurred as expected in the context of a static background noise. In Experiment 1B, we examined whether the onset of repetitive background changes disrupted preview benefit. In each trial, a static background noise was changed to a dynamic background noise, simultaneous with the appearance of the search display. In Experiment 1C, we assessed the effects of repetitive changes; a dynamic background noise was thus presented throughout each trial. Experiments 1A, 1B, and 1C were conducted in separate sessions. All participants took part in Experiment 1A in the first session. After that, half of the observers completed Experiment 1B in the second session and Experiment 1C in the third session, whereas the others completed Experiment 1C in the second session and Experiment 1B in the third session. The three sessions were run on the same day.

3.2. Results

For Experiments 1A–1C, the results of the ANOVA are summarized in Table 1; search function statistics are summarized in Table 2; and error rates are displayed in Table 3. The search functions for Experiments 1A–1C are depicted in Fig. 4A–C, respectively.

3.2.1. Experiment 1A (no background change)

A 3 × 3 ANOVA for reaction time, with search type (preview, full-baseline, and half-baseline conditions) and set size (4, 8, and 16) as within-subject factors was performed. The main effects of search type and set size were significant in all of the above ANOVAs (Table 1), indicating that the intercepts differed among conditions, and further that the slopes were not flat. The ANOVA also revealed a significant interaction ($F_{4, 44}$ = 24.36), indicating that the search slopes differed across the three conditions. We conducted two separate two-way within-subject ANOVAs, an approach commonly adopted in visual marking studies, to allow for detailed comparison of the different search types. When the reaction time data of the preview and full-baseline conditions were compared, the interaction between search type and set size was significant ($F_{2, 22}$ = 12.67), indicating the presence of preview benefit. The interaction was also significant in the comparison between the preview and half-baseline conditions ($F_{2, 22}$ = 11.8). These results indicate that there was a preview benefit, albeit submaximal, when the items were presented on a background of static random noise.

3.2.2. Experiment 1B (onset of repetitive changes)

As with Experiment 1A, the 3 × 3 ANOVA revealed significant main effects of search type and set size, and also a significant interaction ($F_{4, 44}$ = 9.79). In the separate comparison between the preview and full-baseline conditions, the interaction was not significant ($F_{2, 22}$ = 0.45). In contrast, the interaction was significant in the comparison between the preview and half-baseline conditions ($F_{2, 22}$ = 13.99). Therefore, the slope of 52.2 ms/item observed under the preview condition did not significantly differ from the slope of 57.3 ms/item observed under the full-baseline condition, but did differ from the slope of 32.2 ms/item observed under the half-baseline condition. These results indicate that the onset of repetitive background changes disrupts preview benefit.

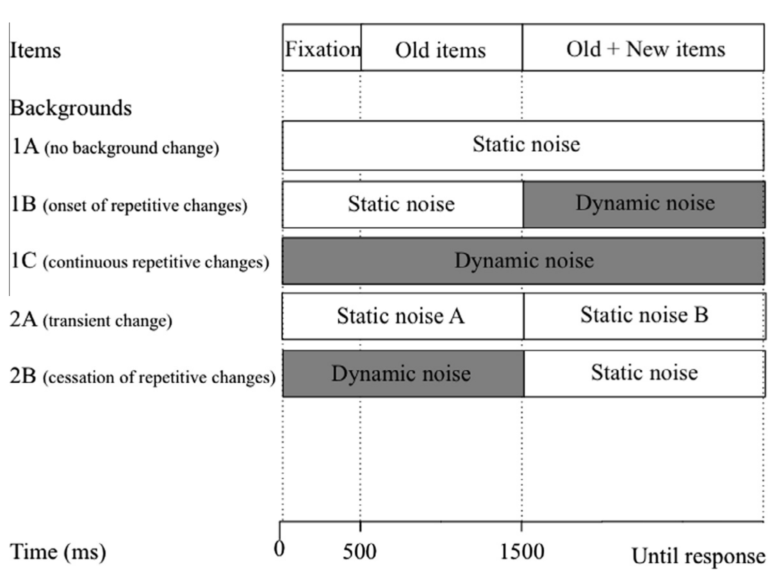

Fig. 3. Schematic diagrams of the stimulus and background sequences of Experiments 1 and 2.

Table 1
ANOVA results for Experiments 1–3, and 5.

	Full vs. Pre vs. Half			Full vs. Pre			Half vs. Pre		
	F	p	ηp^2	F	p	ηp^2	F	p	ηp^2
Experiment 1A (no background change)									
Task type	65.58	.01	.86	57.68	.01	.84	12.24	.01	.53
Set size	89.81	.01	.89	87.24	.01	.89	72.33	.01	.87
Task type × set size	24.36	.01	.69	12.67	.01	.54	11.8	.01	.52
Experiment 1B (onset of repetitive changes)									
Task type	33.96	.01	.76	17.51	.01	.61	19.89	.01	.64
Set size	117.72	.01	.91	112.19	.01	.91	102.96	.01	.90
Task type × set size	9.79	.01	.47	0.45	.64	.04	14	.01	.56
Experiment 1C (continuous repetitive changes)									
Task type	58.94	.01	.84	69.54	.01	.86	10.27	.01	.48
Set size	50.45	.01	.82	52.66	.01	.83	39.53	.01	.78
Task type × set size	29.24	.01	.73	17.28	.01	.61	12.86	.01	.54
Experiment 2A (transient change)									
Task type	47.2	.01	.81	37.38	.01	.77	17.8	.01	.62
Set size	109.07	.01	.91	104.3	.01	.90	85.03	.01	.89
Task type × set size	17.07	.01	.61	9.55	.01	.46	14.69	.01	.57
Experiment 2B (cessation of repetitive changes)									
Task type	47.08	.01	.81	33.24	.01	.75	10.24	.01	.48
Set size	72.68	.01	.87	77.7	.01	.88	55.21	.01	.83
Task type × set size	14.43	.01	.57	6.13	.01	.36	6.9	.01	.39
Experiment 3A (double changes)									
Task type	29.61	.01	.73	18.26	.01	.62	20.67	.01	.65
Set size	82.68	.01	.88	80.54	.01	.88	59.11	.01	.84
Task type × set size	8.99	.01	.45	0.83	.45	.07	12.29	.01	.53
Experiment 3B (triple changes)									
Task type	38.72	.01	.78	21.78	.01	.66	19.97	.01	.64
Set size	58.57	.01	.84	50.7	.01	.82	69.9	.01	.86
Task type × set size	11.79	.01	.52	0.41	.67	.04	18.95	.01	.63
Experiment 5A (before)									
Task type	62.87	.01	.85	71.14	.01	.87	7.42	.05	.40
Set size	79.03	.01	.88	74.3	.01	.87	73.83	.01	.87
Task type × set size	22.18	.01	.67	19.9	.01	.64	10.11	.01	.48
Experiment 5B (after)									
Task type	54.4	.01	.83	53	.01	.83	9.96	.01	.48
Set size	79.5	.01	.88	57.4	.01	.84	83.2	.01	.88
Task type × set size	11.9	.01	.52	16	.01	.59	2.57	.1	.19

3.2.3. Experiment 1C (continuous repetitive changes)

The 3 × 3 ANOVA again revealed significant main effects of search type and set size, and also a significant interaction ($F_{4,\,44} = 29.24$). A separate comparison of the preview and full-baseline conditions also revealed a significant interaction ($F_{2,\,22} = 17.28$), indicating a preview benefit. A significant interaction was also observed in the comparison between the preview and half-baseline conditions ($F_{2,\,22} = 12.86$), indicating that preview benefit was present but submaximal. Therefore, it appears that the presence of continuous repetitive background changes does not disrupt preview benefit.

Table 2
Search function statistics for Experiments 1–3 and 5.

Experiment	Slope (ms/item)			Intercept (ms)		
	Pre	Full	Half	Pre	Full	Half
1A (no background change)	47.0	69.1	31.9	384.4	489.3	458.8
1B (onset of repetitive changes)	52.2	57.3	32.2	383.9	498.4	457.1
1C (continuous repetitive changes)	45.3	64.9	30.7	382.5	434.1	461.3
2A (transient change)	41.0	60.0	27.5	399.2	439.0	457.1
2B (cessation of repetitive changes)	39.6	53.5	26.9	405.1	467.9	456.6
3A (double changes)	49.1	54.2	33.0	478.6	577.9	495.1
3B (triple changes)	56.0	60.4	29.3	368.6	474.9	468.7
5A (before)	49.0	71.3	36.0	386.0	462.7	458.6
5B (after)	45.2	68.3	34.8	435.2	534.1	477.5

Table 3
Mean error rates in Experiments 1–3 and 5.

Experiment	Search type and set size								
	Pre			Full			Half		
	4	8	16	4	8	16	4	8	16
1A (no background change)	2.8	2.2	1.9	0.8	2.2	3.9	3.1	3.6	1.9
1B (onset of repetitive changes)	2.2	2.8	4.2	1.9	1.4	2.8	1.4	2.8	2.5
1C (continuous repetitive changes)	3.3	3.1	3.6	1.7	2.5	2.8	2.5	1.9	3.3
2A (transient change)	1.7	3.3	1.9	2.2	1.1	1.7	2.5	1.7	1.4
2B (cessation of repetitive changes)	2.8	1.9	3.1	0.6	0.8	1.1	3.9	1.4	1.4
3A (double changes)	2.2	1.7	4.2	1.7	2.5	1.7	1.7	3.3	0.8
3B (triple changes)	2.2	1.1	1.4	1.1	1.9	3.1	1.7	1.9	0.8
5A (before)	1.9	1.7	3.1	1.4	0.8	1.1	2.8	1.9	2.2
5B (after)	1.4	1.9	2.2	1.7	1.4	2.8	1.7	2.5	2.8

3.3. Discussion

We investigated whether participants were able to ignore task-irrelevant repetitive changes in the scene, namely the onset of repetitive changes and continuous repetitive background changes, while they were performing a preview search task. First, we checked that a preview benefit could be obtained using a static background noise (Experiment 1A). Second, when a static background noise was altered to a dynamic background noise, the search slope of the preview condition was not significantly different from that of the full-baseline condition (Experiment 1B),[1] indicating that the onset of repetitive background changes simultaneous with the delivery of new items disrupted preview benefit. If only marked locations and sudden changes are monitored during visual marking, as suggested by Jiang, Chun, and Marks (2002), we would expect that preview benefit would be reduced by changes within the objects themselves, but not by changes in the background region. Our results are inconsistent with this prediction because, when the search items were superimposed on the background noise, the visual system could not filter out the onset of irrelevant repetitive changes in the background region. Third, because continuous repetitive changes did not disrupt preview benefit (Experiment 1C), the disruption in visual marking could not be explained by impoverished item visibility *per se*, as introduced by dynamic noise. Rather, our finding that previewing and visually marking old items is advantageous in visual search, when the background is dynamically updated throughout visual inspection, represents psychophysical evidence for the robustness and usefulness of visual marking occurring in the context of more realistic scenes. Fourth, in all experiments, the slope of the preview condition was steeper than that of the half-baseline condition; i.e., the preview benefit was present but submaximal in the presence of background noise. We discuss the possible causes of imperfect preview benefit in the General Discussion. The overall findings indicate that the onset of repetitive background changes, simultaneous with the onset of new items, may play a key role in abolishing preview benefit.

4. Experiment 2: does a single transient change, or the cessation of repetitive changes, reduce preview benefit?

In Experiment 1, preview benefits were fully abolished by the onset of repetitive background changes simultaneous with the onset of new items. In Experiment 2, we examined whether certain other types of background changes occurring at this time could impact upon preview benefit (Fig. 3).

Previous studies have demonstrated that a transient change in old items disrupts preview benefit, but a background change does not (Jiang, Chun, & Marks, 2002). This suggests, in conjunction with our results from Experiment 1, that the onset of repetitive changes in the background causes disruption of preview benefit. However, it could be argued that changes in the background noise patterns used in the present study were much more conspicuous compared with changes in the luminance of the background used by Jiang, Chun, and Marks (2002). If this were the case, a single transient change in background noise patterns might be sufficient to disrupt preview benefit. To test this possibility, we assessed preview benefit under conditions in which search items were superimposed on a static background noise refreshed only once, simultaneous with the appearance of the search display (Experiment 2A).

It is also important to ascertain whether the cessation of repetitive background changes reduces preview benefit. Abrams and Christ (2003) reported that neither motion offset nor continuous motion attracts attention during visual search, whereas motion onset does. Thus, the onset signal of repetitively changeable events may act as a trigger to capture attention. However, controversy remains regarding whether motion offset captures attention. For example, Kawahara, Yanase, and Kitazaki (2012) demonstrated that, when observers searched for a green letter embedded in a rapid sequence of heterogeneously colored nontarget letters, both the irrelevant onset and offset of motion captured attention. Therefore, it is important to investigate whether the cessation of

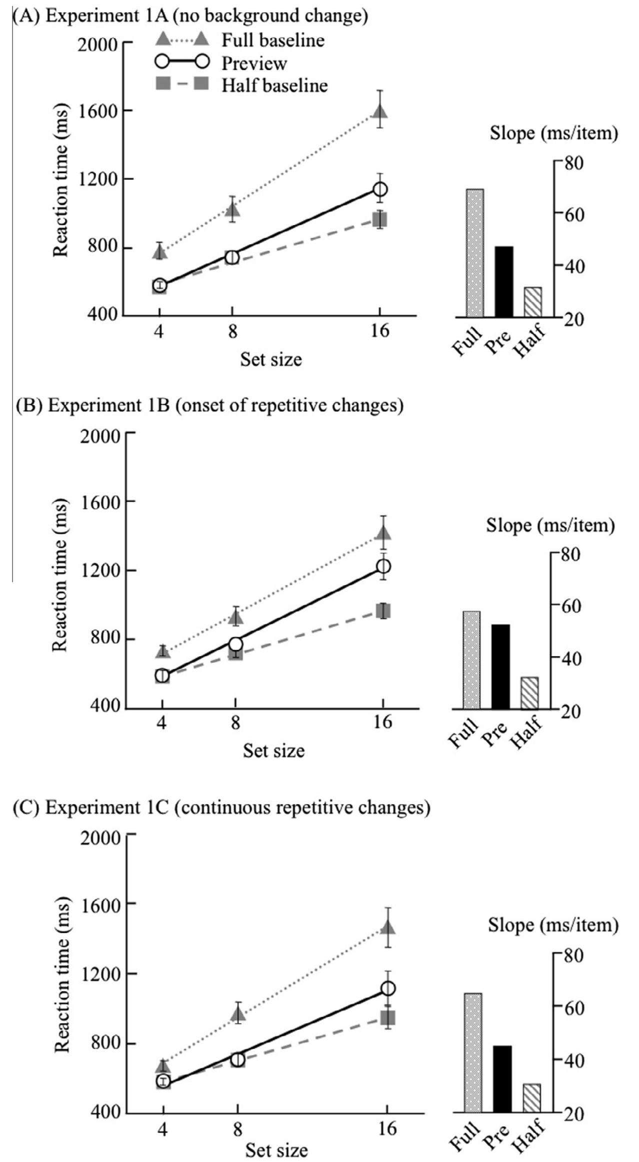

Fig. 4. Mean reaction time as a function of set size under the preview, full-baseline, and half-baseline conditions. (A) Experiment 1A (no background change); (B) Experiment 1B (onset of repetitive changes); (C) Experiment 1C (continuous repetitive changes). Error bars represent standard error. The bar chart indicates the slope of reaction time as a function of set size.

[1] In Experiment 1B, the intercept of the search function for the preview condition was lower than for the full-baseline condition. This may be because, only under the preview condition, the onset of old items 1 s prior to the onset of new items provided an additional set-size-independent temporal cue for the arrival of the second set of items (Fig. 1). Therefore, participants could commence searching more rapidly under the preview vs. full-baseline condition, resulting in a decrease in intercept. Furthermore, previewing old items may enhance ability to distinguish new items from the background, because old items would provide an additional discrimination cue. Such a discrimination process should be conducted only before a search process commences, and would only affect the intercept (Wolfe et al., 2002). We further discuss the possible causes of a lower intercept under the preview condition of Experiment 4.

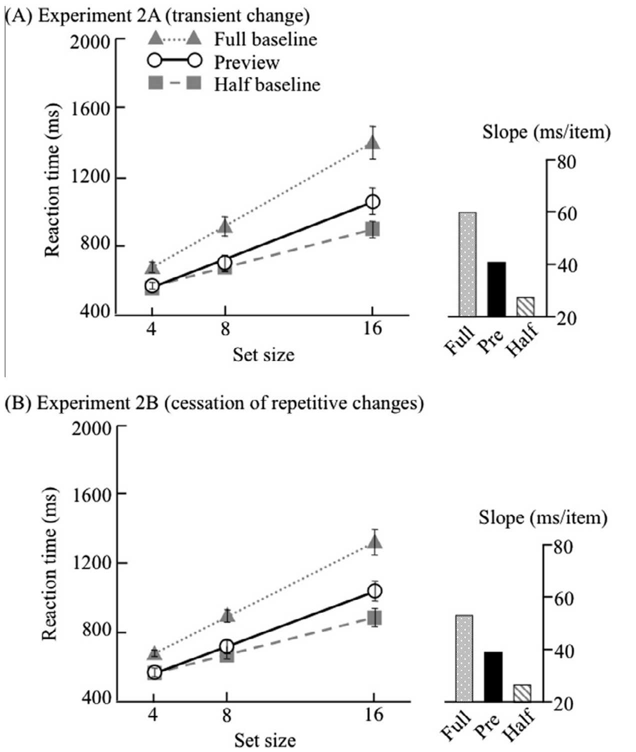

Fig. 5. Mean reaction time as a function of set size under the preview, full-baseline, and half-baseline conditions. (A) Experiment 2A (transient change); (B) Experiment 2B (cessation of repetitive changes). Error bars represent standard error. The bar chart indicates the slope of reaction time as a function of set size.

repetitive background changes reduces preview benefit (Experiment 2B).

4.1. Methods

Eleven observers (aged 19–32 years) who were naïve to the purpose of the study participated, in addition to the first author. Six of the naïve observers and the first author had participated in Experiment 1 before participating in this experiment. In Experiment 2A, search items were superimposed on a static background noise, the pattern of which was changed simultaneous with the appearance of the search display; in Experiment 2B, dynamic noise was changed to static noise at this time. Experiments 2A and 2B were conducted in separate sessions. Half of the observers completed Experiment 2A prior to Experiment 2B, whereas the others completed Experiment 2B prior to Experiment 2A.

4.2. Results and discussion

For Experiments 2A and 2B, the results of the ANOVA for reaction time are summarized in Table 1; search function statistics are summarized in Table 2; and error rates are displayed in Table 3. The search functions for Experiments 2A and 2B are depicted in Fig. 5A and B, respectively.

4.2.1. Experiment 2A (transient change)

The 3 × 3 ANOVA revealed a significant interaction ($F_{4,44}$ = 17.07). In the comparison between the preview and full-baseline conditions, a significant interaction was again identified ($F_{2,22}$ = 9.55), indicating the presence of a preview benefit. The interaction was also significant in the comparison between the preview and half-baseline conditions ($F_{2,22}$ = 14.69); therefore, the preview benefit was submaximal. These results indicate that the preview benefit persisted during the transient change in background noise.

4.2.2. Experiment 2B (cessation of repetitive changes)

The 3 × 3 ANOVA revealed a significant interaction ($F_{4,44}$ = 14.43). In the comparison between the preview and full-baseline conditions, a significant interaction was again identified ($F_{2,22}$ = 6.13), thereby indicating the presence of a preview benefit. The interaction was also significant in the comparison between the preview and half-baseline conditions ($F_{2,22}$ = 6.9), indicating that the preview benefit was submaximal. These results indicate that the preview benefit persisted during the change from a dynamic to a static background noise.

For both Experiments 2A and 2B, the search slope of the preview condition was shallower than that of the full-baseline condition, and was steeper than that of the half-baseline condition, demonstrating that these manipulations did not fully abolish preview benefits.

5. Experiment 3: how many repetitive changes are sufficient to abolish preview benefit?

The results thus far have indicated that preview benefit is reduced by the onset of repetitive changes (Experiment 1B) but not by a single transient change (Experiment 2A). One important question concerns the number of repetitive background changes required to abolish the preview benefit. In one previous study, in which the shape of old items changed, search performance declined commensurate with an increasing number of repetitive changes. The preview benefit was completely abolished by a third repetition (Watson, Compton, & Bailey, 2011). To test the possibility that the first few repetitive background changes might be sufficient to abolish preview benefit, we manipulated the number of repetitive background changes.

5.1. Methods

Eleven observers (aged 19–32 years) who were naïve to the purpose of the study participated, in addition to the first author. One observer and the first author had participated in Experiment 1, 2 and 4 before participating this experiment. In each trial, transient background changes occurred either twice (Experiment 3A) or three times (Experiment 3B) following the appearance of the search display, with an inter-stimulus interval of 100 ms. Experiments 3A and 3B were conducted in separate sessions. Half of the observers completed Experiment 3A prior to Experiment 3B, whereas the others completed Experiment 3B prior to Experiment 3A.

5.2. Results and discussion

For Experiments 3A and 3B, the results of the ANOVA for reaction time are summarized in Table 1; search function statistics are summarized in Table 2; and error rates are displayed in Table 3. The search functions for Experiments 3A and 3B are depicted in Fig. 6A and B, respectively.

5.2.1. Experiment 3A (double changes)

The 3 × 3 ANOVA revealed a significant interaction ($F_{4,44}$ = 8.99). In the comparison between the preview and full-baseline conditions, the interaction was not significant ($F_{2,22}$ = 0.83). In contrast, the interaction was significant in the comparison between the preview and half-baseline conditions, ($F_{2,22}$ = 12.3). Therefore, double changes in background disrupted preview benefit.

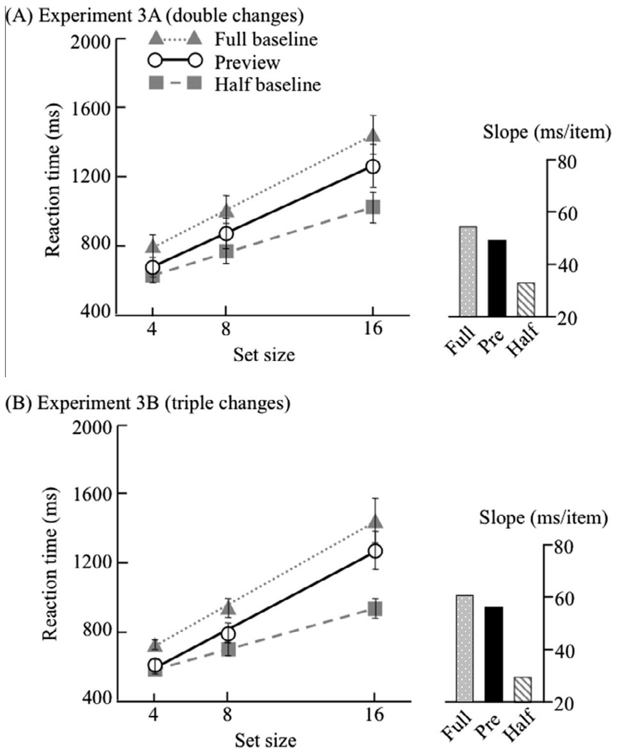

Fig. 6. Mean reaction time as a function of set size under the preview, full-baseline, and half-baseline conditions. (A) Experiment 3A (double changes); (B) Experiment 3B (triple changes). Error bars represent standard error. The bar chart indicates the slope of reaction time as a function of set size.

5.2.2. Experiment 3B (triple changes)

The 3 × 3 ANOVA revealed a significant interaction ($F_{4, 44}$ = 11.8). In the comparison between the preview and full-baseline conditions, the interaction was not significant ($F_{2, 22}$ = 0.41). In contrast, the interaction was significant in the comparison between the preview and half-baseline conditions, ($F_{2, 22}$ = 18.9). Therefore, triple changes in background again disrupted preview benefit.

In Experiments 3A and 3B, when transient background changes occurred either twice or three times following the appearance of the search display, preview benefit was abolished. Thus, the first few repetitive changes in background are sufficient to attenuate preview benefit. Because a single transient change in background was not sufficient to affect preview benefit (Experiment 2A), more than one background change is required to abolish preview benefit. However, future examination is needed to ascertain whether there is a qualitative distinction between the single and multiple changes or whether the disruptive influence is more gradually elevated with an increasing number of changes. In any event, this finding is consistent with the view that the visual marking system regards repeating changes as more important than a brief, single, transient change (Watson, Compton, & Bailey, 2011).

6. Experiment 4: how critical is the onset timing of a dynamic random-noise background?

The initiation of repetitive background changes fully disrupted preview benefit, whereas continuous repetitive changes did not (Experiments 1B and 1C). This indicates that the onset of repetitive changes in the background plays a key role. However, it remains unclear whether preview benefit disruption occurs only when the onset of background changes is synchronized with the onset of new items. It has been previously demonstrated that preview benefit is partially or fully attenuated when attention is withdrawn from the locations of old items during the preview period (Humphreys, Watson, & Jolicœur, 2002; Olivers & Humphreys, 2002; Watson & Humphreys, 1997). According to this perspective, attention must be paid to old distractors during the preview period to prevent their competing for selection with new items. However, Jiang, Chun, and Marks (2002) demonstrated that, when the interval between the changes in old items and the onset of new items was 107 ms, the change in old items did not disrupt preview benefit. Therefore, it is possible that preview benefit disruption occurs only when the onset of background changes is synchronized with the onset of new items.

We also independently manipulated the numbers of new and old items. In Experiment 1, the number of items was identical (two old items + two new items in the smaller set; eight old items + eight new items in the larger set), such that a search slope could depend on either the number of old items, the number of new items, or both. Therefore, despite apparent disruption of the preview benefit, a beneficial decrease in search slope might have persisted, only being attenuated by increases in the search slope induced by other factors (c.f., Jiang, Chun, & Marks, 2002). For example, if it took longer to allocate attention to new items commensurate with increases in their number, the search function against total set size (old items + new items) would increase irrespective of the number of old items on which the effect of visual marking should depend. If so, the lack of a difference in the search slopes of the preview and full-baseline conditions might not be evidence for an absence of preview benefit. This possibility can be tested by ascertaining whether the search slope is sensitive to the number of old items that are supposedly excluded from the search; accordingly, we manipulated the numbers of old and new items independently.

6.1. Methods

Fifteen naïve observers (aged 19–32 years) and the first author participated. Three of the naïve observers and the first author had participated in both Experiments 1 and 2 before participating in this experiment, one observer had participated only in Experiment 1, and two observers had participated only in Experiment 2. The stimuli, apparatus, and procedure were identical to those of Experiment 1B, with the following exceptions. First, we systematically manipulated the interval between the onset time of dynamic random noise and the onset time of new items under the preview condition. The interval between the initiation of dynamic background noise and the onset of the new items was either

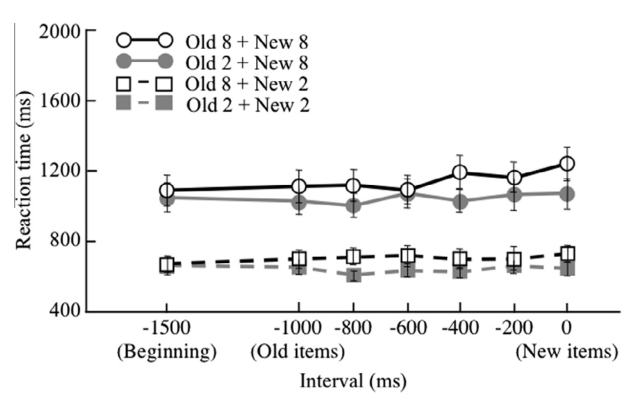

Fig. 7. Mean reaction time as a function of interval between the onset of repetitive changes and new items, using a combination of new and old set sizes as a parameter. A negative interval is indicative of conditions under which the onset of repetitive changes in background preceded the onset of new items. Error bars represent standard error.

−1500, −1000, −800, −600, −400, −200, or 0 ms. Negative intervals indicate conditions under which the onset of repetitive changes in background preceded the onset of new items; the 0 ms interval indicates that a static background noise was changed to a dynamic background noise simultaneous with the appearance of the search display. The −1500 ms interval condition was identical to the preview condition employed in Experiment 1C, in which the dynamic random noise was presented throughout each trial. Second, the numbers of old and new items were orthogonally manipulated, and reaction time, as a function of the number of old items, was used to evaluate whether preview benefit disruption occurred. Specifically, four combinations of set sizes were used; i.e., two old + two new (set size = four); eight old + two new (set size = 10); two old + eight new (set size = 10); and eight old + eight new (set size = 16). The maximal preview benefit occurs when the reaction time for two old items is the same as that for eight old items, because old items do not affect search time. By contrast, preview benefit disruption occurs when the reaction time for eight old items is longer than that for two old items. Each block consisted of a total of 56 trials (seven intervals × four set-size combinations × two trials) presented in a random order. Participants completed nine such blocks.

6.2. Results

Fig. 7 displays mean reaction time as a function of the interval between the onset of repetitive changes and the onset of new items, with set size conditions included as an additional parameter. The mean error rates are summarized in Table 4. The results of the ANOVA for reaction time are summarized in Table 5. Reaction time increased commensurate with increasing numbers of old items at 0 ms, but not at −1500 ms. Furthermore, the difference in reaction time, between either two or eight old numbers, increased as the interval shortened. The ANOVA for reaction time, with interval, number of old items and number of new items as within-subject factors, revealed significant main effects of interval ($F_{6,\,90} = 2.76$), number of old items ($F_{1,\,15} = 27.26$), and number of new items ($F_{1,\,15} = 88.7$). Furthermore, the interaction between interval and number of old items was significant ($F_{6,\,90} = 2.44$). All of the other interactions were non-significant.

The simple main effect of number of old items was significant at −1000, −800, −400, −200, and 0 ms ($F_{1,\,105} > 5.66$), with a trend toward significance at −600 ms ($F_{1,\,105} = 3.29$), but was not significant at −1500 ms. It should be noted that, if visual marking ceased, the number of old items presented would affect search performance. This occurred whenever a static background noise was changed to a dynamic random noise during the preview period. In contrast, the number of old items did not affect performance when a dynamic random noise was presented throughout each trial. Furthermore, the simple main effect of interval was significant for the old number of 8 ($F_{6,\,180} = 3.7$), but not significant for the old number of 2 ($F_{6,\,180} = 1.51$). Multiple comparisons, using Ryan's (1960) method, revealed that, for the old-item number of 8, reaction time at 0 ms was longer than it was at −1500 ms, −1000 ms, and −600 ms (t_{180} >.3.08, p < .05).

Table 4
Mean error rates in Experiment 4.

Interval	Numbers of new and old items			
	New 2		New 8	
	Old 2	Old 8	Old 2	Old 8
−1500 ms	2.8	1.7	2.3	4.0
−1000 ms	2.0	3.7	3.4	2.6
−800 ms	2.6	2.6	3.4	3.4
−600 ms	4.8	3.1	3.4	2.3
−400 ms	3.1	1.4	2.6	1.4
−200 ms	2.6	3.7	4.0	2.3
0 ms	2.6	2.3	3.1	4.0

Table 5
ANOVA results for Experiment 4.

	F	*p*	ηp^2
Three-way ANOVA			
Interval	2.76	.02	.16
Number of old items	27.26	.01	.65
Number of new items	88.7	.01	.86
Interval × number of old items	2.44	.03	.14
Interval × number of new items	1.35	.24	.08
Old item number × new item number	2.68	.12	.15
Three-way	0.86	.53	.05
Simple main effect of old item number			
−1500 ms	0.6	.44	.01
−1000 ms	5.66	.02	.05
−800 ms	15.54	.01	.13
−600 ms	3.29	.07	.03
−400 ms	17.82	.01	.15
−200 ms	5.86	.02	.05
0 ms	21.14	.01	.17
Simple main effect of interval			
Old 2	1.52	.17	.05
Old 8	3.7	.01	.11

6.3. Discussion

Reaction time increased commensurate with an increasing number of old items, when a static background noise was changed to a dynamic background noise simultaneous with the appearance of the search display (0 ms), but did not increase commensurate with an increasing number of old items when dynamic background noise was presented throughout each trial (−1500 ms). These findings are consistent with those of Experiments 1B and 1C, and indicate that initiation of repetitive changes disrupts preview benefit. Regarding the time course of the influences of repetitive background changes, preview benefit disruption was not limited to the precise time at which the new items were delivered, but rather occurred up to 1 s prior to their delivery. This suggests that task-irrelevant background changes can influence attention for up to 1 s, presumably by automatically diverting it away from the locations of old items. This is consistent with the view that participants need to attend to old distractors during the preview period to prioritize the selection of new items (e.g., Watson & Humphreys, 1997). Furthermore, the disruptive influence of the background increased with greater temporal contiguity between the initiation of repetitive changes and new items. It is likely that, when initiation occurs too early, participants re-attend to the locations of old items. Preview benefit is known to occur when old and new items are separated by at least 400 ms (e.g., Watson & Humphreys, 1997); longer preview periods do not have deleterious effects (Braithwaite et al., 2006). If the initiation is sufficiently close to the delivery of the new items, however, the visual system presumably lacks the time required to re-attend to the old locations, thereby losing the preview benefit.

The present results indicate that the onset of repetitive changes increases reaction time as a function of the number of old items that are supposedly excluded from the search. This is inconsistent with the notion that initiation of repetitive changes in the background is unrelated to the number of old items, but rather modifies the influence of the number of new items in a manner not directly relevant to preview benefit (c.f., Jiang, Chun, & Marks, 2002). For example, if it took more time to allocate attention to new items commensurate with increases in their number, the search function against total set size (old items + new items) would increase irrespective of the number of old items upon which the effect of visual marking should depend. However, the results indicated the opposite: the initiation of repetitive changes modified the search function against the number of old items, in accordance with preview benefit disruption, but did not alter the search function against the number of new items.

7. Experiment 5: does an asynchronous single change of background disrupt preview benefit?

Preview benefit was disrupted by the double or triple transient changes of background occurring at the onset of new items (Experiment 3) but was not abolished by a single transient change synchronized with the onset of new items (Experiment 2A), suggesting that at least two background changes are required to abolish the benefit. However, a single background change might be sufficient for the disruption of preview benefit if it is asynchronous with the onset of new items, with the change occurring either before or after the onset of new items. If the disruption of the preview benefit observed in Experiment 3A was due to this second change, i.e., an asynchronous background change that occurred 100 ms after the onset of new items, then this change alone should be sufficient for the disruption of preview benefit. To examine this hypothesis, we manipulated the timing of a single background change.

7.1. Methods

Eleven naïve observers (aged 19–33 years) participated, in addition to the first author. The first author had participated in Experiments 1–4 before participating in this experiment. In each trial, a single transient background change occurred 100 ms before (Experiment 5A) or after (Experiment 5B) the onset of new items. These time intervals for the background changes were chosen based on the results of Experiment 3A in which double transient changes starting at the onset of new items disrupted the preview benefit. Experiments 5A and 5B were conducted in separate sessions. Half of the observers completed Experiment 5A prior to Experiment 5B, whereas the others completed Experiment 5B prior to Experiment 5A.

7.2. Results and discussion

For Experiments 5A and 5B, the results of the ANOVA for reaction time are summarized in Table 1; search function statistics are summarized in Table 2; and error rates are displayed in Table 3. The search functions for Experiments 5A and 5B are depicted in Fig. 8A and B, respectively.

7.2.1. Experiment 5A (before)

The 3 × 3 ANOVA revealed a significant interaction ($F_{4,44}$ = 22.18). In the comparison between the preview and full-baseline conditions, the interaction was significant ($F_{2,22}$ = 19.86), indicating the presence of preview benefit. The interaction was also significant in the comparison between the preview and half-baseline conditions, ($F_{2,22}$ = 10.11); therefore, preview benefit was submaximal. These results indicate that the preview benefit persisted despite a single change in background noise when this change occurred before the onset of new items.

7.2.2. Experiment 5B (after)

The 3 × 3 ANOVA revealed a significant interaction ($F_{4,44}$ = 11.88). In the comparison between the preview and full-baseline conditions, the interaction was significant ($F_{2,22}$ = 16.04), indicating the presence of preview benefit. The interaction did not reach significance in the comparison between the preview and half-baseline conditions, ($F_{2,22}$ = 2.57); therefore preview benefit was maximal. These results indicate that the preview benefit persisted in spite of a single change in background noise when this change occurred after the onset of new items. Taken together, we confirmed that at least two background changes are required to abolish preview benefit.

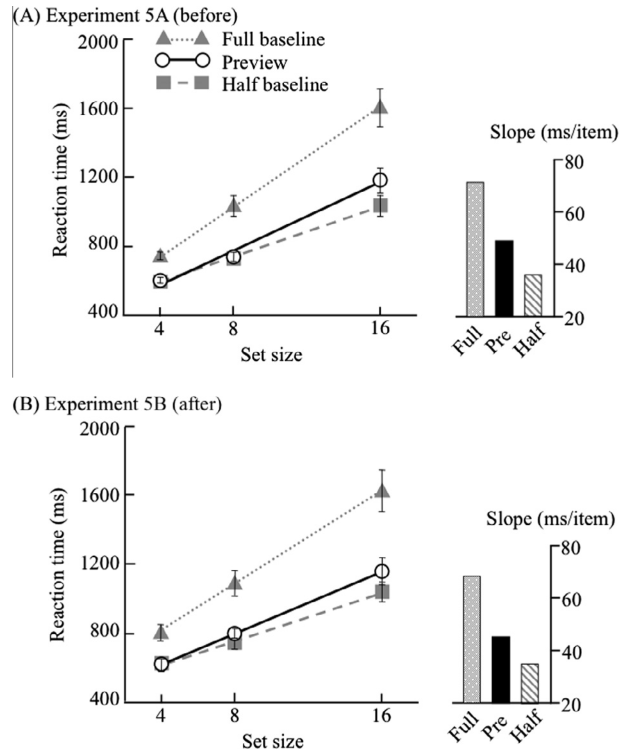

Fig. 8. Mean reaction time as a function of set size under the preview, full-baseline, and half-baseline conditions. (A) Experiment 5A (before); (B) Experiment 5B (after). Error bars represent standard error. The bar chart indicates the slope of reaction time as a function of set size.

8. General discussion

The present study examined whether the preview benefit conferred by visual marking still occurs in the presence of task-irrelevant changes in the background. Experiments 1 and 2 demonstrated that preview benefit is attenuated by the onset of repetitive background changes (Experiment 1B), but not by either the continuous repetitive changes themselves (Experiment 1C), a single transient change (Experiment 2A), or the cessation of repetitive changes (Experiment 2B). Furthermore, when transient background changes occurred either only twice (Experiment 3A) or three times (Experiment 3B) following the appearance of the search display, preview benefits were completely abolished, indicating that the first few repetitive background changes are sufficient to attenuate preview benefits. Furthermore, reaction time increased commensurate with increasing numbers of old items when a static background noise was changed to a dynamic noise during the preview period, but no increase occurred when a dynamic random noise was presented throughout each trial. This underlines the particular importance of the onset of dynamic random noise (Experiment 4). In addition, the initiation of repetitive background changes did not need to occur simultaneously with the onset of new items to affect preview benefit. Lastly, we demonstrated that an asynchronous single change was not sufficient for the disruption of the preview benefit (Experiment 5).

As noted in the Introduction, the types of stimulus change necessary to confer preview benefit remain subject to conjecture. Jiang, Chun, and Marks (2002) demonstrated that a transient change in old items disrupted preview benefit, but a background change (i.e., a change in the luminance of the background grid) did not, suggesting that the visual system monitors only marked locations, and any sudden changes therein. In contrast, we observed that the onset of repetitive changes in the background disrupted preview benefit. This suggests that dynamic changes in the background region might also be monitored by the system responsible for visual marking. One possible explanation for differences between the present study and that of Jiang, Chun, and Marks (2002) is that certain types of background change may induce different outcomes. As demonstrated in Experiment 3, preview benefit was disrupted following at least two or three repetitive background changes. It is likely that, even though the visual system detects a single transient change occurring within the background region, a single change is not sufficient to affect attention and thereby attenuate the effects of visual marking. Most importantly, the present study demonstrated that background information is monitored by the system responsible for visual marking, such that the memory template corresponding to old distractor positions is abolished by sufficiently large background changes. To our knowledge, our study is the first to demonstrate full disruption of the preview search in response to changes in a task-irrelevant background.

The present study supports the hypothesis that the contents of the memory template reflect current visual inputs, and further that the template is updated whenever any significant changes occur in those inputs (Watson & Humphreys, 1997). Because a search-task-irrelevant transient stimulus, such as background changes, may nevertheless act as a warning signal conveying information critical for survival, it is reasonable to suggest that attentional resources are automatically allocated to such a change, thereby reducing preview benefit in the current search task. Although previous studies have demonstrated that preview benefits disappear when old items alter their shape during the preview period (e.g., Watson & Humphreys, 1997, 2002), such a change might trigger increases in the "targetness" (e.g., von Mühlenen & Lleras, 2007, Yantis & Egeth, 1999) of old items. If this were the case, participants might have attended to the locations of old items because they confused change in the old items with the appearance of targets. The present study employed completely task-irrelevant changes, and demonstrated that the task-irrelevant change itself, synchronized with the onset of new items, plays a key role in abolishing preview benefit, thereby suggesting that the memory template underlying visual marking is modified not only by bottom-up activities at the locations of old items, but also by previously unattended-to, dynamic events in the scene.

The present study provides evidence that the onset of a dynamic noise has a strong impact on preview benefit. A similar impact of the onset signal has also been demonstrated in the attentional capture literature (Abrams & Christ, 2003, 2005). According to Abrams and Christ (2003), neither motion offset nor continuous motion attracts attention during visual search, in contrast to the onset of motion. Likewise, the onset of a dynamic noise may serve as a trigger to capture attention. Therefore, the same system may be exhibiting attentional capture, and also removing preview benefit; it is possible that these two phenomena are causally linked by an attentional capacity limit.

The phenomenon of preview benefit is thought to depend on visual marking at old locations using a spatial memory template (e.g., Watson & Humphreys, 1997). How does the memory template monitor marked locations and sudden changes occurring therein? We propose that marked locations and the background are differently, but simultaneously, monitored. Specifically, marked locations, and changes occurring therein, may be monitored through bidirectional, direct links to the memory template (Watson & Humphreys, 1997). The memory template inhibits attentional processing at marked locations, and input changes at marked locations are sent to the memory template. The inhibitory template is occasionally removed because ignoring such changes is not of benefit. In contrast, the memory template may not directly monitor the changes at the level of the background. Background changes may capture attention (Kawahara, Yanase, & Kitazaki, 2012; Franconeri & Simons, 2003; von Mühlenen & Lleras, 2007) and require a proportion of the attentional resources allocated to the template (Watson & Humphreys, 1997). When the onset of repetitive changes is detected by the system, resource allocation to the memory template may be re-evaluated, because the observer may now wish to attend to the background. If the background change is transient and insufficiently large, no change occurs in attentional resource allocation, because such changes are insufficiently interesting. In contrast, if the background changes are repeated, attentional resources to the memory template may be reduced gradually. Therefore, as continual changes in the background are detected by the system, inhibition at marked locations gradually diminishes, such that preview benefit is abolished. However, if there is sufficient time between the onset of the motion and the appearance of the new items, viewers can re-engage attention on the previewed items with enough time to recreate the memory template, thereby leading to a reappearance of the preview effect. Our data from Experiment 4 suggest that this process takes about 1 s.

The argument that the initiation of a dynamic event sequence captures attention, and diverts attentional resources from the visual marking process, is consistent with the conclusion of Watson and Humphreys (2005), who examined the effects of the onset of task-irrelevant objects presented immediately prior to the onset of new items, using a similar experimental paradigm to that of the present study. The onset of irrelevant discs, outside of the spatial focus of attention, reduced preview benefit only when the discs were the same color as the new items; i.e., when they were able to capture attention. The preview benefit persisted if the irrelevant discs were the same color as the old items, or if they did not share the same color with any items.

The presence of preview benefit during the continuous repetitive changes observed in the present study is consistent with findings reported in the change blindness literature. Using a change detection task, Becker and Vera (2007) demonstrated that repeated irrelevant changes are less disruptive to change detection for a target object if such irrelevant transients occur prior to the target change, suggesting that they are attentionally filtered as distracting signals. Similarly, the present study has demonstrated that if there is sufficient time between the onset of the repetitive changes and the onset of new items, prolonged repetitive changes do not affect the preview benefit. Thus, the same system may play a role in recreating the memory template for visual marking and in filtering out irrelevant transients, recovering from initial distraction with sufficient time for attentional re-engagement.

In contrast with the maximal preview benefit observed when search items are presented in blank displays (e.g., Watson & Humphreys, 1997), the preview benefit in the presence of background noise was submaximal. This may be due to the complexity or heterogeneity of the background. When search items are superimposed on background noise, old items likely need to be presented for a longer period of time for the maximal benefit to emerge. When search items are more difficult to individuate, as they are at equiluminance with the background, the preview items have to be shown for at least 3 s to yield preview benefit (Braithwaite et al., 2006). Alternatively, the imperfect preview benefit observed in the present study may be due to the lack of a color difference between the old and new items. When old and new items are of the same color, the preview benefit is submaximal (e.g., Al-Aidroos et al., 2012). The color difference between the old and new items is a more important cue for preview benefit than the location difference (Meinhardt & Persike, 2014). Further studies are needed to clarify these issues.

In conclusion, our results demonstrate that task-irrelevant background events reduce the preview benefit for search efficiency when a static background noise is changed to a dynamic background noise. In contrast, continuous repetitive changes, a single transient change, or the cessation of repetitive changes, have no effect. This suggests that the onset of task-irrelevant background changes disrupts either the attentional processes underlying inhibitory visual marking of old items, or the allocation of attention to new items. Altered search performance, as a function of the number of old items, suggests that the former hypothesis—that disruption of visual marking occurs following background changes—is more likely to be correct. We propose that such disruption stems from an attentional capacity limit, which requires re-evaluation of resource allocation in response to a potentially interesting event in the outer world, be it at marked object locations or in the background.

Acknowledgments

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